Metalization: An End-User's Perspective

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ABSTRACT

At Frito-Lay, we think of metalization as one of the most dynamic and impactful technologies of the last two decades. With metalized film, we have enjoyed a multiplicity of benefits—light, moisture, and oxygen barrier, as well as its complementary graphic effects. For over 15 years metalized polyester and metalized polypropylene have performed these functions consistently in our snack and bakery laminations. At the same time there have been consistent differences in the base economics, supply, and utilization of these great products. The learning curve and the challenges for metalized polypropylene have been much greater, involving extensive effort to improve metal adhesion, bonding layer technology, processing dynamics, and general fitness for use. And while metalizers have focused on a mosaic of processing considerations, our efforts have focused traditionally on basefilm economics and evaluation of flat film barrier properties. Today, we seek not only to maintain these foci, but to significantly increase our understanding of the role of metalized film in finished package performance. We seek balance between the intrinsic shelf-life of a product, finished package barrier properties, package hermeticity, and initial nitrogen flush levels. We seek a deeper understanding of the mechanical property differences between plastics and metal in this context. And we must understand the material machinery interface, in film manufacture, in metalizing, in converting, and in bagmaking. At Frito-Lay, we think the future is bright for metalization. Bright, in terms of potential advances in fundamental metalization technology, as well as advances in converting, bagmaking, and end use.

INTRODUCTION

When you use 3 trillion sq. in. of packaging material per year, you do have a "perspective". And now, we are developing a worldwide perspective. We estimate that the present worldwide production of metalized film is about 7 billion square meters, about 2.5 billion in the U.S., about 2.1 in Europe, and the balance, principally in Asia and Australia. We are very, very interested in your industry, and in this product we call metalized film.

From our perspective, metalization as a technology is definitely an "impact" technology. In the last two decades, three areas of technology,

- Metalization
- Film coextrusion
- Printing & coating technologies

have had significant and ubiquitous impact on packaging. But the metalization process clearly stands out as the "home run hitter", the most dynamic and impactful of all, because of the multiplicity of benefits it generates.

- Light barrier
- Moisture barrier
- Oxygen / aroma barrier
- Complementary graphics effects

The importance of these, and their impact on the quality of our products has been described, [1], [2], [3]. In this chart, (Figure 1), we can see the multiplicity of benefits at work—in a synergistic way. Unlike any other component of packaging, metalization can deliver a cost effective combination of benefits that really improves product quality.

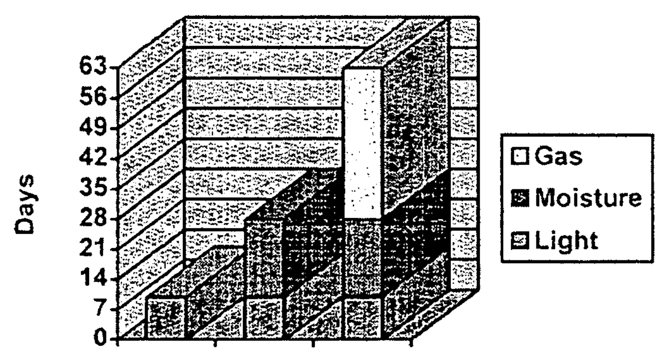

Figure 1. Relative effect of barrier properties on shelf-life of potato chips.

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But we are cautiously optimistic. We speak with trepidation, because our perspective also reveals the fragile side of this wonderful technology. One the one hand, we see the great improvements in barrier that result from metalization, (Table I.).

Table I. Barrier improvements through metalization; Basefilms vs. PVdC vs metal.

	OTR (flat) at 23°C/0%RH (cc/m²day)	MVTR (flat) at 30°C/80%RH (g/m²day)
12 μm PET	77	42
PVdC/PET	6.5	3.3
mPET	.77	.31
18 μm OPP	3100	3.9
PVdC/OPP	7.7	.93
mOPP	31	.31

But on the other, we are fully capable of destroying much of the benefit in the bagmaking, (Table II.).

Table II. Barrier degradation of metalized film as a result of bagmaking; OTR in cc/m²day at 23°C/0%RH; MVTR in g/m²day at 30°C/80%RH.

Example Laminations	OTR (flat)	OTR (formed)	MVTR (flat)	MVTR (formed)
mPET	1.4	5.11	0.12	0.23
mPET	0.9	11.9	0.15	0.33
mOPP	150	460	0.54	0.93
mOPP	15	250	0.15	0.62
mOPP	15	60	0.15	0.20

So today, barrier degradation has been a focal point of much of our recent effort. And much of this paper reviews data from our investigations of the barrier loss mechanisms.

BARRIER DEGRADATION

Barrier degradation has been more of a problem with metalized polypropylene (mOPP) versus metalized polyester (mPET), which has shown good environmental barrier, but at a higher cost. Improved mPET sealants have resulted in excellent film performance but basic economic and supply limitations have persisted for Frito-Lay. On the other hand, mOPP has been economically more attractive, and more available. The learning curve for mOPP has generally been steeper, involving issues with metal adhesion, bonding layer technology, processing dynamics, and general fitness for use considerations. All of the remaining information in this paper refers to metalized OPP.

Fundamentally, Frito-Lay recognizes four main mechanisms of barrier degradation:

c Pinholes
c Scratching
c Crazing
c Stretching

And they seem to occur in several different scenarios (Table 3).

Table III. Metalization barrier loss scenarios.

	Metalizing	Printing/ Lamination	Bagmaking	Distribution
Pinholes	x			x
Scratching	x	x		
Crazing	x	x	x	x
Stretching		x	x	

Notably, cracking and crazing remain as potential problems in most scenarios. Stretching would seem to be avoidable given today's modern digital drive technology, but it appears that (delicate) metalized film is still at risk in ways other than from simple web tension.

Pinholes in the metal layer (or pin-windows in the metalized film) appear to develop most often during metalizing and prior to downstream processing (e.g. lamination) either from (a) metal scuffing off the protruding areas which are load-bearing points when film is in the form of a commercial roll, or (b) abrasion from a point protrusion on the opposing adjacent layer of unmetalized film. The resulting pin-windows can be quite deleterious and numerous on a substrate which is not suitable for high barrier metalization. The material depicted in Figure 2. is such a material. The total amount of defect area is greater than 5% of the total, and resulting barrier properties are high and out of range for "high barrier" applications.

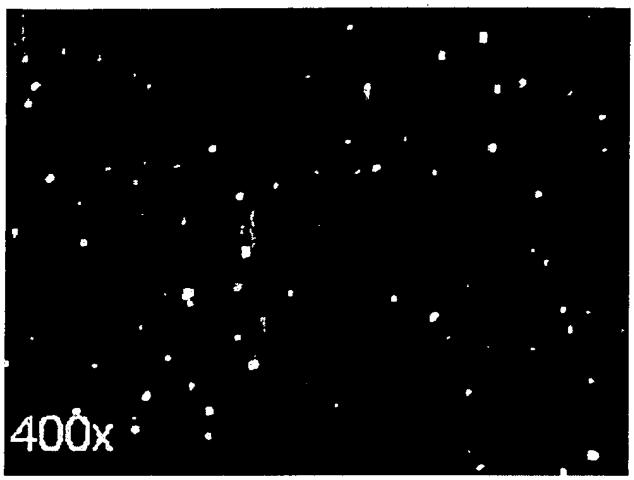

Figure 2. Typical mOPP in 1988 showing more than 5% defect area via pin-windows; Rough topography, R(a) > 30 nm.

Figures 3 & 4 illustrate an extraordinarily large pin-window that was caused by a semi-subterraineal additive particle which was abraded. Figures 5 & 6 illustrate a set of features common to some mOPPs.

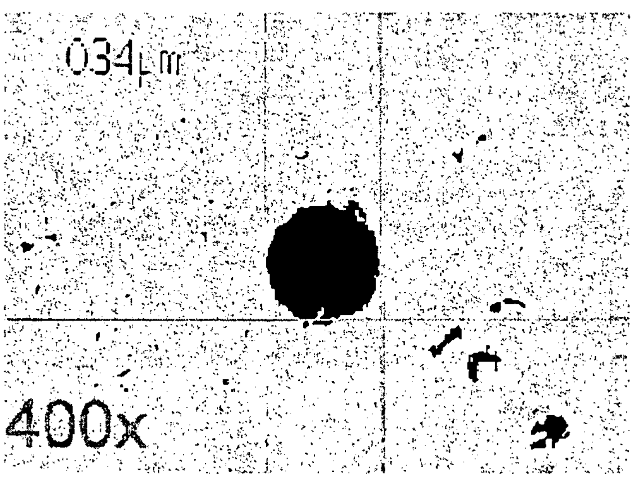

Figure 3. Microscopic view of a 34 μm pin-window in a 1990 sample of mOPP at 400x magnification.

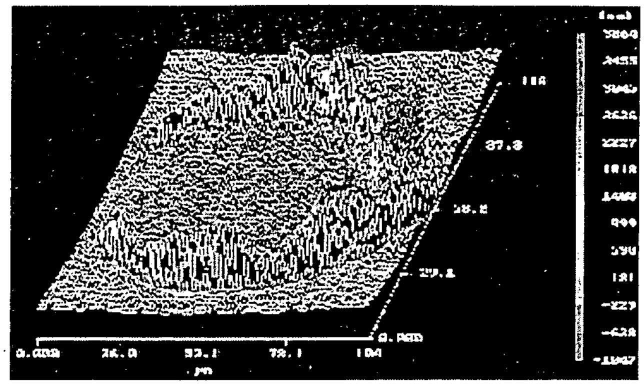

Figure 4. Topographical microscope image of 34 μm pin-window, (WYKO RST database).

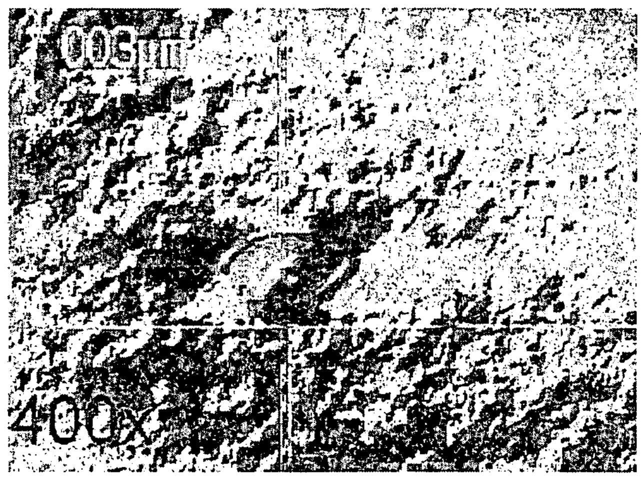

Figure 5. Microscope view of a 3 μm pin-window in a 1992 sample of mOPP at 400x magnification.

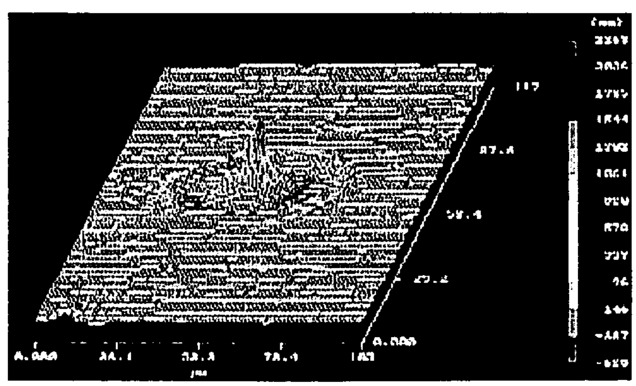

Figure 6. Topographical image of a 3 μm pin-window with characteristic "sombrero" features, (WYKO RST database).

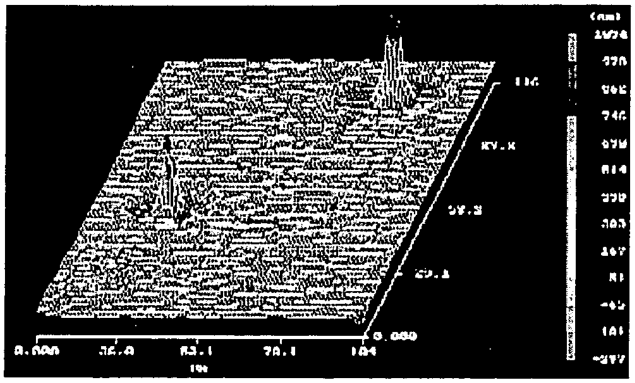

Figure 7. Topographical image of typical 1992 mOPP with small pin-windows, but less than 5% defect area, (WYKO RST database).

A lot of effort has gone into identifying these features [4] and in-chamber coating technologies have been developed which "flatten" these films and improve barrier performance, [5], [6], [7]. As Figure 7 illustrates, some high barrier films do have small pin-windows, resulting from generally smaller surface defects, and they do exhibit good flat sheet barrier properties and process capability. However, the best performing high barrier mOPP films are consistently flat, have few surface defects, good metal adhesion, and are process capable, (see Figure 8.).

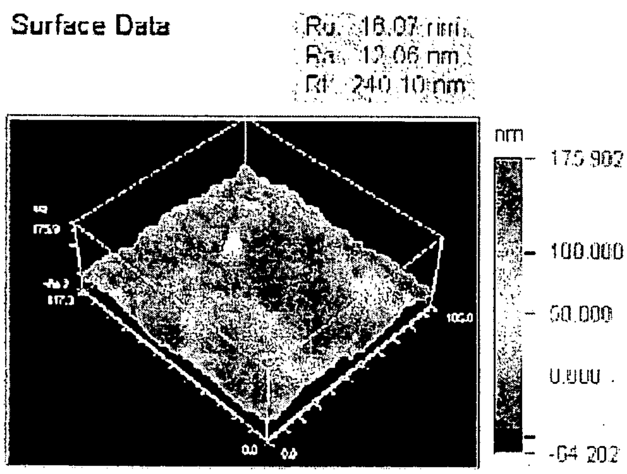

Figure 8. Topographical image of high barrier mOPP in 1996; Small pin-windows, low % defect area, R(a) < 20 nm; OTR = 45 cc/m²day at 22.8°C/0%RH; CPk=1.33.

Crazing is another common cause of barrier degradation in metalized film. Crazing is itself a visible recording of the effect of stress and stretching of the film. Figures 9 & 10 show the typical light microscopic view of crazing in its most common form at scales of 100x and 400x.

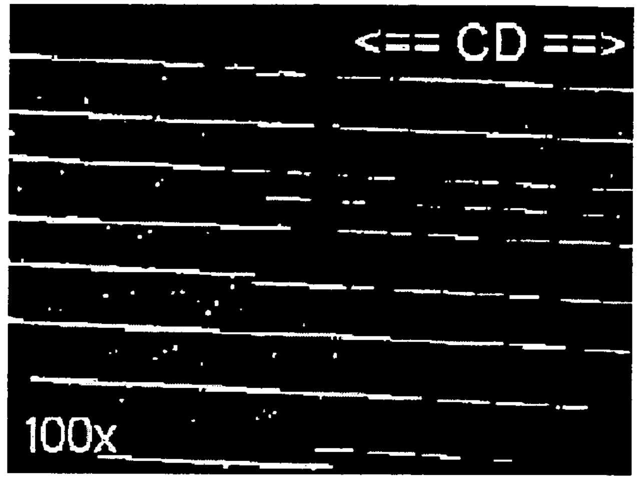

Figure 9. Back-lit microscope image of severely crazed mOPP showing cross-directional striations in the metal.

Figure 10. 9 μm stria at higher magnification.

Electron micrographs taken by other researchers have also shown that the same effect at approximately 1/10 this scale, showing crazing stria on the order of 0.5 μm (500 nm) in width [7]. These data suggest that smaller micro-cracks may be quite numerous, but less likely to be visually observable. This would parallel our own observations of micro-peaks—that small ones can occur in great numbers, and not necessarily cause pin-windows.

Stretching (elongation) of the base film, or of a lamination, may cause loss of barrier without visible signs of crazing. Clearly, we are limited in our visual investigations by the smallest wavelength of available incident light, and much of the damage may not be "viewed" with common microscopic techniques. In Figure 11, the effect of stretching on optical density is shown for two typical snack food laminations.

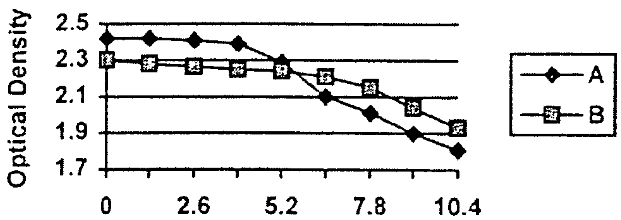

Figure 11. Decline in optical density with elongation of mOPP laminations.

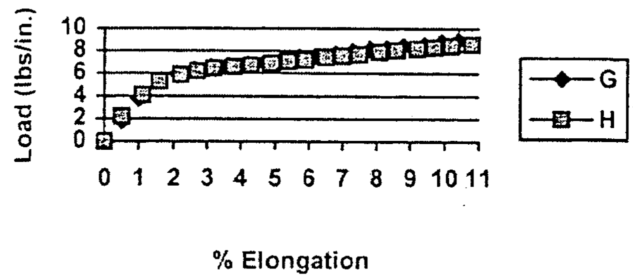

Figure 13. Load vs elongation for typical mOPP laminations; Yield point estimated at 2%.

Neither sample under stress exhibited crazing, but there was a consistent loss of optical density as elongation increased.

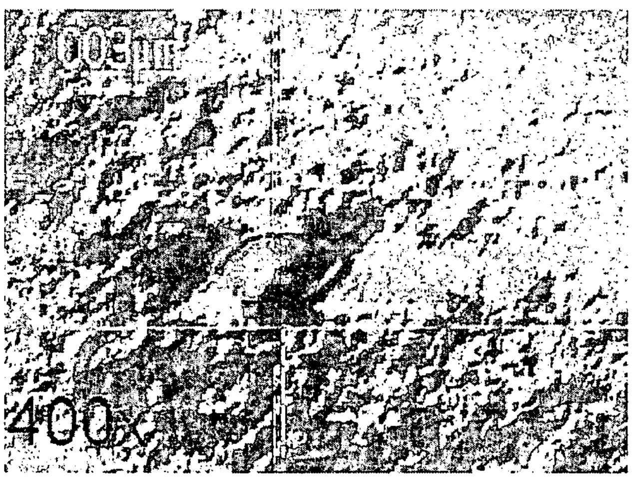

Figure 12. Increase in oxygen transmission rate (OTR) with elongation of mOPP; OTR at 73°F/0%RH.

Similarly, in Figure 12, the samples showed measurably increased loss of oxygen barrier with increased elongation without visible crazing. Since the molecular sizes of the common permeant molecules (.30-.46 nm) are roughly three orders of magnitude smaller than observable micro-cracks, it seems plausible that unseen defects are contributing greatly to permeation.

The stress-strain curve for a common snack food lamination (Figure 13) shows the characteristic pattern for plastic films—a sharp rise in the elastic region, followed by a gradual rise until the break point is reached.

It is important to note that beyond the elastic limit, the original dimensions of the plastic are not recovered when stress is removed. This point appears to be in the 2-3% range for these laminations. This corresponds with the breakaway point in the OTR vs % Elongation data shown in the previous data (Figure 12). We believe that somewhere around 2.5% elongation, unrecoverable damage begins to occur in the barrier layer.

These circumstances create multiple challenges. We need to identify high stress areas in our bagmaking operations. We need equipment designs / modifications which eliminate them. Film suppliers are challenged to improve films which more effectively resist in stressful film handling environments. Collectively, we need to better understand the mechanical properties of distantly differently components like these plastic films and aluminum in this context. Generally, we need a much deeper understanding of the interface between metal and film in the metalizing process, and we are challenged to effect performance improvements as measured by these simple tests on finished consumer goods.

ROBUST, HIGH BARRIER, METALIZED FILM

A robust film is one whose flat sheet barrier properties are unaffected by end use application. From our perspective, the key considerations for making a robust mOPP fall into three areas: Substrate, Metalizer, and Knowledge of the End-Use Environment. Besides the mechanical considerations, the substrate must have an acceptable metal bonding surface in terms of functionalization and topography. The metalizer must have modern web handling capability, be capable of consistent metal lay down, and be adaptable to modern in-chamber coating & treatment technologies. And the end-use environment must be defined mechanically.

Some examples of bonding layer preparation for metalization are listed. Surface treatment technologies like corona, flame, and plasma are commonly mentioned and have been discussed in detail by others [7], [8]. The objective is to improve metal adhesion by removing mechanically weak boundary layer materials and contaminants and imparting polar functionality. Use of coextruded skin layers is also effective in controlling surface functionality for metalization.

The topographical considerations mentioned in this paper are based mainly on polypropylene. Flatter films with fewer, smaller surface disruptions have been better performers.

Metalizer considerations are known to us mainly in terms of features that directly control end-use film performance. Obviously flat, wrinkle-free film is critical, and web handling is critical. Consistent metal lay-down and deposition control systems are also critical.

In-chamber treatment technology requires extra consideration because it can enable less expensive substrates to perform at significantly higher levels than normal. The benefits of these technologies have been described in many of the references cited at the end of this paper.

Finally, end-use considerations are mainly mechanical in nature because films are flexible and fragile, and are used in fairly aggressive end-use environments, competing with many other consumer products, many of which are rigid, fairly durable containers. But some measures of success are relatively simple. For example, moisture or oxygen gain of the finished package can be used as a direct measure of robustness. These same measures are routinely used to characterize products at different stages of consumer acceptability.

CONCLUSIONS

Metalization continues to be a key technology, demonstrating continuous improvement, and significant potential for future development. Metalizing equipment has improved greatly and is in sync with modern control, drive, and PLC technology. In-chamber coating and pretreatment technology could elevate overall process capability to a new level.

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